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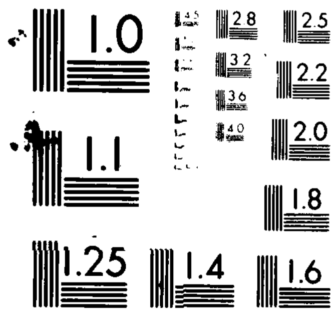

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LEVEL II

2

DEVELOPMENT OF A MULTIPLE LINEAR
REGRESSION MODEL TO FORECAST FACILITY
ELECTRICAL CONSUMPTION AT AN
AIR FORCE BASE

Fred H. Weck, Major, USAF

LSSR 68-81

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Various Department of Defense (DOD) and Air Force facility project improvement programs exist to allow existing and new facilities to be more energy efficient to meet the energy reduction goals imposed by the Congress and the President. For the Air Force to effectively satisfy the goals of electrical energy conservation, it is necessary to identify those variables that influence facility electrical energy. The current lack of a satisfactory method to predict electrical usage at Air Force bases is reducing our ability to manage future energy conservation. The author, using the technique of multiple linear regression, examined the role that the variables of heating and cooling degree days, square footage of facilities, and base population take in determining the amount of electricity consumed by fifteen Air Force bases in the Continental United States. Regression analysis revealed that linear models can be developed that are good predictors of facility electrical energy consumed by an Air Force base.

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DEVELOPMENT OF A MULTIPLE LINEAR REGRESSION MODEL TO FORECAST FACILITY ELECTRICAL CONSUMPTION AT AN AIR FORCE BASE

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

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By

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CHAPTER I

INTRODUCTION

Background

Ever since the Organization of Petroleum Exporting Countries decided, in late 1973, to drastically curtail exports of crude oil to the United States and other western industrialized nations, there has been a growing awareness among Americans that the days of abundant and inexpensive energy sources are gone, most likely forever. This awareness has led to concern, both in the military and civilian sectors of our society, about the ramifications of more expensive energy sources in the future.

If there are any certainties in the complex world of energy and its potential impact on our society, this statement by former Secretary of Defense Dr. Harold Brown, is one of them:

> . . . there is no more serious threat to the long-term security of the United States and to its allies than that which stems from the growing deficiency of secure and assured energy resources [23:28].

The seriousness of the problem transcends the bounds of political parties. The strategic importance of the Middle East as the major source of the free world's oil imports has been emphasized by the current Secretary of Defense Casper W. Weinberger in testimony before the Senate Armed Services Committee: "The umbilical cord of the industrialized free world runs through the Strait of Hormuz into the Arabian Gulf and the nations which surround it [10:B11]."

In August 1977, the Congress reaffirmed the dangers of our dependence on insecure supplies of foreign oil. Specifically, in enacting the Department of Energy Organization Act, the Congress declared that the "energy shortage and our increasing dependence on foreign energy supplies present a serious threat to the national security of the United States [33:3]." Similarly, Stansfield Turner, former director of the Central Intelligence Agency, told the Senate's Committee on Energy and Natural Resources in April 1980:

> Moscow no doubt will make an intense effort to obtain oil at concessionary prices from the oil producing countries through barter deals, sometimes involving arms sales. More forceful action, ranging from covert subversion to intimidation, or, in the extreme, military action, cannot be ruled out [22:13].

The Central Intelligence Agency went on to state that there is a high probability that acts of nature, human error or deliberately targeted terrorist attack will interrupt the flow of oil in one or more of the oil exporting nations during the next several years (4:31).

The strong concern voiced by former Defense Secretary Brown and the current Secretary of Defense

Weinberger may very well stem from the fact that the Department of Defense uses 85 percent of all the energy consumed by the federal government, and 38 percent of that energy requirement is for military installations (6:2).

Though this research effort is concerned with electrical power (not as an energy source, but as a carrier of energy), there is a subtle, yet real connection between availabilty of electrical power and America's dependency upon imported oil. The electrical power produced by utility companies accounts for approximately 25 percent of the total energy requirements in the United States, but will account for 37 percent of the total requirement by 1985 (18:17). Unfortunately, about 45 percent (9:148) of this electrical power is produced by utility companies with generating plants that burn oil or natural gas, both of which will continue to become more scarce and which will continue to be supplied in part by imports from foreign countries (18:3). Since oil and natural gas have been available until the last several years at artificially low prices, the use of alternate abundant fuels such as coal and reactor quality fissionable materials have not been vigorously pursued. Concerns about adverse affects to human and natural resources environment caused by coal and nuclear power plants have also inhibited the development of power plants using these abundant domestic fuels. Consequently, electric utility companies are very vulnerable to another curtailment (accidental, human error, terrorist strike or war) of petroleum imports. While it is difficult to predict the future capacity of nuclear generating plants, with timely siting, permitting and construction, huge increases in nuclear power availability are possible--and huge increases were predicted in the early 1970s. Even after problems and longer-than-anticipated lead times began reducing that optimism, projections in 1975 and 1976 showed nuclear power quadrupling by 1985 and increasing sevenfold by 1990 (4:17). Projections made late, in 1977-78, still showed strong growth but much less than earlier--closer to a fourfold increase by 1990 (4:17). As would be expected, more recent projections since the Three Mile Island accident and its aftermath are even more pessimistic. The breakdown of the reactor cooling system at the Three Mile Island nuclear electric generating plant in the Spring of 1979 made it clear that all power plants are vulnerable to unforeseen circumstances which may disrupt electrical power for extended periods of time (16:3). Consequently, current projections generally limit potential nuclear growth to those plants already under construction or in permit review. This growth would roughly triple nuclear energy by 1990, from 1.3 million barrels of oil per day equivalent (mbde) in 1979 to nearly 4 mbde in 1990 (4:17).

Little support now can be found for the huge 1990 growth rates projected earlier.

It is apparent then that the source of commercial electrical power is sensitive and vulnerable to both interruptions in the supply of imported oil and the future number of nuclear power generating plants ultimately placed into operation.

The Defense Advanced Research Projects Agency predicted, as far back as 1972, that an energy shortage would "have deleterious effects on national security, particularly in economic, political, and military terms [11:29]." As the increase in energy consumption at military facilities paralleled the increased usage in the American economy as a whole, the Agency was particularly concerned with the fact that "nearly all U.S. military installations met their energy need through procurement of off-site commercial supplies [11:12]." This being the case, military facilities were not only susceptible to curtailments in the supply of electrical power and petroleum-based fuels caused by oil and gas shortages generated by foreign suppliers, but were also susceptible to curtailments caused by labor strikes, utility plant generating equipment failures, natural disasters, and even price disputes (16:4). In addition, military installations are generally not guaranteed an allocation of electricity during an energy shortage, as are police departments, fire departments, hospitals, and other facilities considered critical by the civilian community (19:26). Yet Air Force regulations currently require the use of existing commercial utility sources whenever economically feasible, rather than developing Air Force power sources (28:4). The United States Army's Construction Engineering Research Laboratory stated that,

> . . . an installation cannot economically compete with a utility company, because the utility company can use its much larger demand base and diversity to obtain large economies of scale [8:10].

Consequently, military installations will probably continue to depend upon commercially supplied electrical power for many years in the future. Military installations comprise a variety of owned and leased facilities--office buildings, hospitals, commissaries, family housing, storage facilities, aircraft simulators, laboratories, and runways, to name a few. Installation operations require the use of energy for both facility operations and process activities. Facility energy is energy principally used for heating, ventilation, cooling, hot water, and lighting for building and personnel protection, personnel comfort and safety, general administration, or housekeeping activities (6:83). Process energy is energy not used for buildings operations. Sources of facility energy include, but are not limited to, electricity, natural gas, coal and oil. Of the 185.5 trillion

Btu used for installation operations energy in FY 80, 55.8 percent (103.6 trillion Btu) was electrical power (24:113). According to the FY 80 Defense Energy Information System II (DEIS II), the Air Force used over 8,931,000,000 kilowatt hours to satisfy the electrical energy demands of military facilities (34). This consumption of electricity during FY 80 cost the Air Force over $400,000,000, which would have paid for the purchase of fifty-five F-16 fighter aircraft.

Similarly, the U.S. Army consumed over 7,938,137,000 kilowatt hours to satisfy facility energy demands during FY 1980 (29:318). The U.S. Navy required 7,850,000,000 kilowatt hours of electricity for their facilities during FY 80 (32:24).

Energy Conservation

The President and the American Congress realized, in the late 1970s, that a reduction in energy consumption would retard increasing energy costs and enhance our national defense by reducing our dependence on foreign suppliers of petroleum.

In compliance with Executive Order 12003, the National Energy Conservation Policy Act (Public Law 95-619), the Defense Energy Program Policy Memorandums 78-2 and 80-6, the Air Force established specific goals to reduce facility energy consumption at its more than 3,000 installations throughout the world. These goals are to (24:4):

1. Reduce energy usage in existing buildings 20 percent per gross square foot of floor area by FY 1985, 25 percent by FY 1990, 30 percent by FY 1995, and 35 percent by FY 2000, as compared with the FY 1975 level. (The FY 1975 baseline is 0.31853 million Btu/square foot.) (26:27).

2. Installation of least life cycle cost energy conservation retrofits in all buildings with over 1,000 square feet of floor area by 1990.

3. In all "new" buildings (those that had not progressed beyond the 35 percent design level as of 1 March 1979), the Air Force established a goal to achieve a 45 percent reduction in average annual energy use per gross square foot of floor area as compared to the FY 1975 level.

For process activities, energy conservation and efficiency goals are to reduce total process energy use and increase process energy efficiency without degrading mission effectiveness (24:83). Specific goals will be developed by each major command (MAJCOM) as part of its energy plan (24:4).

Energy supply goals for installation operations (both buildings operations and process activities) are to (24:83):

1. Reduce consumption of petroleum-based fuels 30 percent by FY 1985, 35 percent by FY 1990, 40 percent by FY 1995, and 45 percent by FY 2000, as compared to FY 1975 baseline levels.

2. Use coal to provide 10 percent of the energy used in Air Force facilities by FY 1985, 15 percent by FY 1990, 20 percent by FY 1995, and 35 percent by FY 2000.

3. Use renewable energy sources--solar, geothermal and wind energy, or refuse-derived fuel (RDF) and biomass--to provide at least 1 percent of the energy used in Air Force installations by FY 1985, 5 percent by FY 1990, 10 percent by FY 1995, and 20 percent by FY 2000.

An additional goal, established by the Air Force in compliance with a presidential memorandum dated 10 April 1979, was to reduce facility energy usage 5 percent during the year ending 31 March 1980 as compared with the year ending 31 March 1979 (26:27).

In FY 1980, the Air Force reduced total facility energy consumption 13 percent, from 213.3 trillion Btu in FY 1975 to about 185.5 trillion Btu (24:113). However, while Table 1.1 reflects an overall downward trend in the amount of energy used for facilities, the percent electricity for any one year actually increases with time, which indicates that the aggregate consumption of the other types of facility energy (i.e., fuel oil, natural

TABLE 1.1

INSTALLATION OPERATIONS ENERGY USAGE BY FUEL TYPE [24:113; 26:28]

	Energy Usage					
Fuel Type	FY 1975	FY 1976	FY 1977	FY 1978	FY 1979	FY 1980
<u>Electricity</u>						
Trillions of Btu	110.60	104.40	105.51	104.47	102.35	103.6
Billions of kWh	9.53	9.00	9.10	9.01	8.82	8.9
Percent of Yearly Total	(51.8)	(51.3)	(53.0)	(53.6)	(53.8)	(55.8)
<u>Fuel Oil</u>[a]						
Trillions of Btu	43.25	41.53	38.26	36.62	34.46	30.9
Millions of bbl	7.42	7.13	6.57	6.29	5.92	5.3
<u>Natural Gas</u>						
Trillions of Btu	44.12	42.66	40.43	39.76	39.79	38.2
Billions of SCF	42.79	41.37	39.21	38.56	38.59	37.0
<u>Propane</u>						
Trillions of Btu	0.43	0.41	0.17	0.29	0.31	0.2
Millions of bbl	0.11	0.10	0.04	0.07	0.08	<0.1
<u>Coal</u>						
Trillions of Btu	14.16	13.51	13.68	13.40	12.68	12.2
Millions of short tons	0.58	0.55	0.56	0.55	0.52	0.5

[a]Fuel oil comprises distillates and residuals used to support facility requirements.

TABLE 1.1--Continued

Fuel Type	Energy Usage					
	FY 1975	FY 1976	FY 1977	FY 1978	FY 1979	FY 1980
Purchased Steam						
Trillions of Btu	0.75	0.83	0.97	0.49	0.52	0.5
Billions of Pounds	0.54	0.60	0.70	0.35	0.37	0.3
Total (Trillions of Btu)	213.31	203.34	199.02	195.03	190.10	185.5
Savings from FY 1975 baseline (Trillions of Btu)	-	9.97	14.29	18.28	23.21	27.8

gas, propane, coal and purchased steam), is decreasing faster than electricity.

Undoubtedly, a large part of the facility energy reductions are due to completed engineering projects involving retrofitting facilities. A significant amount of the facility alteration projects were accomplished under the Energy Conservation Investment Program (ECIP). Major General William D. Gilbert, Director of Engineering and Services, HQ USAF, in testimony before the Subcommittee on Military Construction, House of Representatives, stated that

> . . . the first keystone of our energy program is an aggressive Energy Conservation Investment Program, which is carefully structured and closely monitored to reduce our facility consumption by 12% in 1985 compared to 1975 baseline levels [27:1A2].

General Gilbert went on to state that:

> Parallel to ECIP, which is part of the Military Construction Program, we have initiated a command and base sponsored Operations and Maintenance (O&M) program intended to reduce our energy consumption by an additional 8% by 1985. Our O&M program includes energy saving projects rather small in nature, annual mechanical system inspections and tuneups and public relations programs which make base personnel more aware of how they can individually save energy [27:1A3].

Table 1.2, from the Air Force Facility Energy Plan, FY 76-FY 85, forecasts the funding requirements necessary, by program, to meet the aggressive program goals mentioned earlier. As Table 1.2 reflects, ECIP and O&M projects form the bulk of the funding avenues, at

TABLE 1.2

ESTIMATED ENERGY PROGRAM COSTS [25:vii]
(Active Forces, MFH, Guard, and Reserves)

	Fiscal Year ($ Million)											
Program Goal	76	77	78	79	80	81	82	83	84	85	Total	% of Goal
Energy Supply Assurance	-	-	1.5	3.9	0.2	3.6	4.5	-	-	-	13.7	100
Alternate Fuel Conversion	-	-	-	23.1	-	12.4	86.5	92.0	76.9	131.4	422.2	100
Advanced Energy Technology	-	-	-	1.2	1.0	52.0	103.0	107.0	110.0	112.0	487.2	100
Energy Optimization	68.0	42.5	40.3	56.3	53.8	146.1	147.6	138.2	103.0	140.0	899.8	100
ECIP	62.0	36.5	34.3	44.3	23.8	72.1	78.6	85.4	46.7	42.0	524.7	100
O&M	5.0	5.0	5.0	10.0	15.0	40.0	40.0	40.0	40.0	40.0	240.0	
Metering	-	-	-	-	-	6.0	4.0	3.0	2.0	2.0	17.0	N/A
Other	1.0	1.0	1.0	2.0	15.0	20.0	20.0	20.0	20.0	20.0	120.0	N/A
Joint DOD/DOE Initiatives (Air Force Cost)						8.6	16.5	50.0	50.0	1.0	126.1	-
Totals	68.0	42.5	41.8	84.5	55.0	214.7	353.1	396.2	346.6	348.4	1951.0	-

least up through FY 81. After that date, emphasis will be given toward alternate fuel conversion.

Pursuing further facility energy conservation will remain a significant challenge in the foreseeable future (27:1.A.7). As mentioned earlier, the percentage of Air Force facility energy requirements satisfied by electricity is growing at about 0.8 percent a year. To effectively satisfy the goals of energy conservation within the framework of facility project alteration programs (i.e., ECIP, O&M), it is necessary to identify those variables that influence facility electrical energy. There is lacking a vehicle by which future electrical consumption can be forecasted. Tracking energy use after-the-fact is one thing, but predicting future demand is much more difficult. Yet, such a forecasting model is a necessary precursor to effectively evaluating the success of meeting energy reduction goals, both present and proposed. The current lack of a satisfactory method to predict electrical usage at Air Force bases is reducing the effectiveness of our ability to manage future demand with the goal of reducing the future amount of electricity consumed and paid for with taxpayers' dollars.

Specifically, a reliable mathematical model would:

1. Provide decision makers, from the base civil engineer and his staff, up to HQ USAF, with a tool for forecasting the changes in a base's electrical consumption

when the base is subjected to prolonged periods of adverse weather, significant changes in the base population (i.e., during large scale military exercises) and increases or decreases in the number of base facilities. Once forecasted consumption was quantitied, the base civil engineer's staff could determine the effect on the base's present (or proposed) utility budget. As a result, critically short financial resources would not sit idle in a utilities budget if the forecasted electric consumption did not require the full amount.

2. Provide higher headquarters decision makers with the necessary information to determine the long-range electrical utility costs of a mission beddown at a base. An estimate of future electrical demand over the lifetime of proposed facilities supporting a mission beddown would add greater credibility to the facility electrical consumption estimates in engineering project justification documents.

3. Provide better estimates of seasonal peak electrical loads which is useful when trying to determine what amount of reserve electrical power capacity should be available to the Air Force base from the commercial electric utility supplier.

Problem Statement

To date, an accurate estimating technique or forecasting model has not been developed to predict the quantity of electricity used by Air Force bases.

Objectives of the Research

The overall objective of this research effort is to identify the most important variables for determining future air base facility electrical consumption.

A companion objective is to use the variables to develop an electrical consumption relationship model or models, and evaluate the model's ability to forecast electrical consumption, which can be used by personnel interested in managing electrical energy consumption and conservation.

Hypotheses/Research Questions

Two hypotheses emerge from the review of pertinent literature (Chapter II). Four research questions will be investigated to support or refute the hypotheses. In order to relate the questions to the problem under consideration, the associated hypotheses and the relevant objectives are listed as follows:

Objective Number 1

Determine if there is a relationship between an Air Force base's electrical consumption and the respective heating and cooling degree days, total square footage of real property facilities, and the base population.

Hypothesis 1. Square footage of facilities, base population, and heating and cooling degree days are correlated with a base's electrical consumption.

Question 1. What is the correlation between heating degree days and electrical consumption?

Question 2. What is the correlation between cooling degree days and electrical consumption?

Question 3. What is the correlation between a base's total square footage and electrical consumption?

Question 4. What is the correlation between a base's population and electrical consumption?

Objective Number 2

Develop a multiple linear regression model to forecast the electrical consumption at an Air Force base.

Hypothesis 2. Consumption of electrical energy on an Air Force base is linearly related to heating and cooling days, base population and facility square footage, as independent variables.

CHAPTER II

LITERATURE REVIEW

Introduction

Prior to describing the research methodology designed to accommodate the objectives described in the previous chapter, a review of relevant literature is required to familiarize the reader with recent studies associated with forecasting electrical demand. Several public and private agencies have attempted various electrical demand forecasting models; however, research of available literature reveals that no model of aggregate electrical demand of an Air Force base has been developed or tested. Nonetheless, each previous effort at forecasting has contributed to the current body of knowledge concerning the prediction of electrical demand.

Results of Agencies Within the Department of Defense

U.S. Air Force

According to the Chief of the Energy Group at the Air Force Engineering and Services Center (AFESC), the AFESC has not accomplished any research in this area (34).

An agency in Headquarters, Air Force Logistics Command (AFLC) has attempted some recent research in energy forecasting. Specifically, in late July 1980, the Chief of the Utilities Division (DEMU), Deputy Chief of Staff, Engineering and Services, requested the Directorate of Management Sciences (XRS), to analyze several years of energy data with a view toward reducing AFLC's energy requirement. DEMU furnished XRS data showing total AFLC energy consumption in Btu equivalents by installation and month from January 1976 through May 1980, along with the number of Heating and Cooling Degree Days. DEMO also furnished data relating to square feet of building floor area, installation population, standard hours and earned hours for industrial facilities (14).

The researchers used regression analysis on the data by utilizing a step-wise multiple regression procedure which sequentially selects independent variables (i.e., Heating Degree Days, Cooling Degree Days, Population, etc.) to be used as predictors for the dependent variable.

The researchers concluded that the only major factor affecting AFLC energy consumption is Heating Degree Days, which statistically overrode all other independent variables used. Specifically, for Hill AFB and Robins AFB, Heating Degree Days was the only variable which significantly predicted total energy. For Newark AFS, none of the variables showed a high level of importance. For Tinker AFB, two variables, Population and Cooling Degree Days, did not appear significant until Heating Degree Days was added into the equation, after which, both Cooling Degree Days and Population showed a higher level of importance. The researchers concluded that this occurrence was due to a correlation among the independent variables, referred to as multicollinearity. Multicollinearity was evident for the Kelly AFB data, except that in that case, only Cooling Degree Days were influenced by the entry of Heating Degree Days into the equation (14).

The researchers believed that one reason that Heating Degree Days was so highly correlated with each base's total energy consumption was that most AFLC facilities were constructed prior to energy conservation becoming a concern to HQ AFLC. The report mentioned the conclusion that Heating Degree Days were perhaps more critical than other factors in that facilities must be heated to a certain level to prevent structural damage while this would not be true for Cooling Degree Days. The researchers believed that while it may be relatively uncomfortable to carry out work activities in higher ambient temperatures, facilities do not normally suffer structural damage (14).

U.S. Army

The United States Army Corps of Engineers' Construction Engineering Research Laboratory (CERL) has recently accomplished a research report analyzing facility energy consumption (30:1). This data was collected between

September 1976 and February 1978 for selected Army buildings at Fort Belvoir, Virginia; Fort Carson, Colorado; and Fort Hood, Texas. The buildings used in the research were representative of seven major energy consumer groups found on Army (and other military) installations: family housing, troop housing, administrative/training, production/ maintenance, medical/dental, storage, and community support facilities (30:8).

Because buildings within each consumer group and among consumer groups varied greatly in size, regression analyses were performed on the basis of Btu and kWh consumed per square foot of building floor area so that comparisons between buildings would be meaningful. The regression analysis method resulted in linear equations giving Btu/sq ft/day and kWh/sq ft/day as a function of Heating Degree Days and Cooling Degree Days for each consumer group (34:9).

Table 2.1 shows a summary of the regression analyses for facility electric consumption with the respective coefficient of determination, when reported.

This research by the Army also resulted in quantifying the average annual energy consumption per square foot for the seven consumer groups at the three installations surveyed by the Army's CERL. Table 2.2 shows a listing of their results.

TABLE 2.1

SUMMARY OF REGRESSION ANALYSES (ELECTRIC) [34:23]

$(E_e = a_2 + b_2 \ (CDD_d))^a$

	a_2	b_2	R^2
Family Housing (air cond)	.01447	.001683	.715
(Nonair cond)	.01659	0	-
Troop Housing (air cond)	.01516	.001275	.674
(Nonair cond) (new--nonmodular and modular)	.0152	0	-
(Nonair cond) (old)	.0065	0	-
Admin/Training (May-Sep)	.0512	0	-
(Oct-Apr)	.0215	0	-
Community Facil (May-Sep)	.0684	0	-
(Oct-Apr)	.0662	0	-
Prod/Maint (May-Sep)	.0235	0	-
(Oct-Apr)	.0293	0	-
Med/Dental (May-Sep)	.0557	0	-
(Oct-Apr)	.0353	0	-
Storage (May-Sep)	.0146	0	-
(Oct-Apr)	.0133	0	-

[a] CDD_d = daily Cooling Degree Days.

TABLE 2.2

AVERAGE ANNUAL ENERGY CONSUMPTION BY CONSUMER GROUP [7:16]

(Energy/sq ft/yr)

	Heating (Btu)	Electric (kWh) Air Cond	Electric (kWh) Nonair Cond
Family Housing	127102.31	8.49	6.06
Troop Housing			
Old	118329.62	NA	2.37
New, nonmodular	62615.02	7.96	5.55
Modular	259257.31	NA[a]	5.55
Administration/ Training	111871.84	12.37	
Community Facilities		24.49	
Fieldhouse and gyms	170148.05		
Clubs and commissaries	139519.96		
Maintenance	208490.24	9.82	
Medical/Dental	200338.61	15.99	
Storage	172640.63	5.04	

[a]Cooling supplied by central plant; individual data are not available.

This research report by the Army concluded that the major use of energy on an installation is based on total energy consumption in family and troop housing. However, the report went on to say that community facilities and maintenance facilities use the greatest amount of energy on a per square foot basis (30:21).

U.S. Navy

According to Dr. Roger Staub at the U.S. Navy Civil Engineering Laboratory at Fort Hueneme, California, the Navy has not yet attempted any research with electrical energy forecasting (21). This appeared to be verified by a careful review of the Department of the Navy's Energy Management Annual Report--June 1981 (32).

Results of Rand Studies

The Rand Corporation has published, over the last decade, several reports on the growth of energy demand. Several of these reports are relevant to the subject of electrical demand forecasting.

The first Rand report, prepared by Mr. Kent P. Anderson, was funded with grants from the National Science Foundation with support from the Environmental Protection Agency and describes the development of a simulation model of U.S. energy demand, supply and price (5:v).

The simulation model has several major characteristics including both short-run and long-run demand and supply mechanisms. Although Mr. Anderson admits that further work remains to be done before the model can be considered a routine tool for prediction, he states that the model is capable of accommodating a wide variety of assumptions about parameter values, future technologies, projected economic and demographic growth as well as foreign supply conditions (5:v).

The model is partly recursive and partly simultaneous. Annual levels of energy production, imports, consumption, and prices are determined by the model simultaneously in an iterative routine. The outcome for any particular year determines long-run marginal costs and values for various parameters that are held constant during the following year. Demand and supply elasticities, economic and population growth are given exogenously (5:v).

Electricity is included in the demand model for the residential, commercial, and industrial user sectors of the nation's economy. No definite conclusions about the research effort were mentioned in the report except that further experimentation with the model was necessary (5:38).

Another research report by Rand published an elaboration of comments on the paper entitled "Economic Estimation of Peak Electricity Demands" by Robert M. Spahn and Edward C. Beauvais which was delivered at the Electric

Power Research Institute Load Forecasting Conference in Aspen, Colorado on 1 April 1977.

The author of the note, Mr. Bridger M. Mitchell, states that Spahn and Beauvais' model of electricity demand was a function of the price of electricity, the price of substitute sources of energy, income and other variables (which were not defined). The report by Spahn and Beauvais, according to Mitchell, concluded that increases in the normal price of electricity encourages reductions in the mean level of electricity usage, but, for a given average usage, provide no incentives to change the within-month variance of usage (15:5).

Several Rand reports on the characteristics of electrical demand were authored by Jan Paul Acton. In November 1978, Rand published a report by Mr. Acton which adopted an econometric study of residential electricity demand which accounted for the declining block tariff. The empirical research reported on was based on micro-level data (as distinguished from aggregate time-series or cross-section data) of residential customers in Los Angeles County serviced by the Los Angeles Department of Water and Power and the Southern California Edison Company, between July 1972 through June 1974 (2:1). By adopting a disaggregated approach to estimating demand equations, the researchers believed they were able to measure the marginal price faced by households, electrical consumption of eight major appliances, and customer income. The report indicated that the researchers' development of regression equations accounted for use of eight major household electrical appliances, weighted by the average monthly consumption of those appliances. A variable was included which addressed the percentage of households with air conditioning along with the percentage with electric heating and were weighted by Cooling Degree Days or Heating Degree Days respectively (2:16).

One small drawback of this Rand research effort was that although Acton et al. incorporated measurements of the ownership of eight types of standard household appliances, no data are available about variations across households in rated capacity or operating efficiency of equipment like air conditioners.

The researchers concluded that the presence of declining block rates in the sale of electricity gives rise to potentially strong biases in empirical investigations of demand which are based on the average price of electricity.

Another Rand report by Acton co-authored by Bridger Mitchell reported on a five-year rate structure experiment conducted on 1800 households jointly by the Los Angeles Department of Water and Power, the Rand Corporation and the U.S. Department of Energy. This report examined the relationship between price and electricity consumed, prediction of demand under different levels of price, and predicting the effects of particular customer characteristics. Time of day and price per kWh were the main variables used. The only conclusion reached in this report was that rate experiments are very complex when compared to traditional load studies (1:19).

Numerous other studies were performed by Rand in the early 1970s prior to the oil embargo of late 1973/early 1974. As a result, the forecasting methodology of these studies did not address the drastic changes in oil prices and the resultant consumer interest in energy conservation.

Results from Commercial Electricity Suppliers

This research effort looked at the electrical demand forecasting methodology of a medium sized commercial electricity supplier, Dayton Power and Light Company, and a large power company, Southern California Edison.

Dayton Power and Light Company

The Dayton Power and Light Company (DP&L), in accordance with the State of Ohio Revised Code and the Rules and Regulations of the Ohio Department of Energy, annually submits a Ten Year Forecast for Electric Generation and Transmission to the Ohio Department of Energy (13).

The principal method involved in the Dayton Power and Light forecasts is econometric modeling. Multiple regression equations were estimated from historical economic and demographic data and utilized in linear equations for the residential, commercial, industrial, and Other Public Authority (i.e., national, state, and local government facilities combined) customer classes (7:16). Military installations are included in the Other Public Authority sector.

DP&L used, in their modeling of Other Public Authority (OPA) electrical consumption, the variables of total U.S. Government Employment, the Ohio Unemployment Rate, and the Real Average Public Authority Electric Price. In this model, fourteen observations were used which were annual consumption values in the OPA sector. Regression of this data indicated a coefficient of determination (R^2) of 0.9898, indicating that the variables used explained almost all of the variation in OPA electrical consumption.

Southern California Edison

The Southern California Edison Company (SCE) submits, on an annual basis, a detailed listing of its electrical demand forecasting methodology to the California Energy Commission. Like Dayton Power and Light, the SCE company uses multiple regression analysis to model electric sales and demand among the various customer classes.

The bulk of SCE's effort concerns forecasting for the residential, commercial, and industrial sectors of SCE's customer population because these three sectors accounted for 83 percent of total kWh sales.

In order to forecast Other Public Authority (OPA) kWh sales, the SCE used OPA sales lagged one year, real OPA average price of electricity, real OPA average price of natural gas and total California government employment as independent variables. Using fourteen annual observations produced a coefficient of determination of 0.9760 (20:TS-67).

A careful review of SCE's forecasting methodology revealed a very comprehensive and statistically sound approach. As one of the ten largest commercial suppliers of electricity in the nation, Southern California Edison was selected by Edison Laboratories Institute as providing the best (based on accuracy and statistical significance) forecasting methodology of any commercial electricity supplier in the nation (3).

For the reader interested in forecasting consumption of other types of energy sources, a separate master's thesis (LSSR 67-81), addresses forecasting consumption of various heating fuels at Air Force bases.

Summary

A review of pertinent literature indicates that a model to forecast electrical consumption at an Air Force base has yet to be developed. The closest efforts toward that goal appear to be the results of the U.S. Army Corps of Engineers' Civil Engineering Research Laboratory (CERL). However, the CERL had data of individually metered facilities as distinguished from aggregate installation square footage of facilities.

CHAPTER III

METHODOLOGY

Overview of Research Design

There were two objectives of this research. The first was to determine the correlation between an Air Force base's electrical consumption and important variables suggested by a careful evaluation of the current literature (30; 2; 21; 31) on electrical consumption (Chapter II). The second objective was to develop a multiple linear regression model, as again suggested by the literature (30; 2; 7; 21) in order to forecast the electrical consumption at a base. Both objectives were met by the use of the technique of multiple linear regression (MLR) since it serves two important functions. First MLR provides a statistical technique for analyzing relationships between a single dependent variable and one or more independent variables (12:357). Second, it provides means for developing a mathematical model which is used to forecast the value of the dependent variable (electrical consumption), based on its relationships with one or more independent variables, i.e., heating and cooling degree days, base population and aggregate facility square footage (17:391). Standard computer subprograms are used to facilitate these analyses and to provide information required for evaluating their results.

Scope

Population and Sample

The population of interest for this research effort consisted of all Air Force bases in the Continental United States, including Air National Guard and Air Force Reserve installations that record their respective electrical power consumption. From this population, the sample consisted of fifteen bases from three major air commands. The bases finally selected fairly represented six of the seven climate zones listed in the Department of Defense (DOD) Domestic Base Factors Report (31). The bases finally selected for the sample also represented various sizes as measured in total aggregate square footage of facilities. The time frame of interest in this research effort was recorded electrical consumption for the period from FY 75 to, and including, FY 81.

The three major air commands representing the bases in the sample (Strategic Air Command, Tactical Air Command and Air Force Logistics Command) have different, yet specific missions. The sample used in this research effort, when categorized according to base size and DOD climate zone, appears in Table 3.1.

TABLE 3.1

ORGANIZATION OF SAMPLE BASES

	ANNUAL COOLING DEGREE DAYS						
	<2000	<2000	<2000	<2000	<2000	>2000	>2000
	ANNUAL HEATING DEGREE DAYS						
	>7000	5500-7000	4000-5500	2000-4000	0-2000	0-2000	2000-4000
Total Facility Square Footage as of Sept 1980	Climate Zone 1	Climate Zone 2	Climate Zone 3	Climate Zone 4	Climate Zone 5	Climate Zone 6	Climate Zone 7
13,362,853							Kelly
11,681,183				Robins			
9,745,897		Offutt					
7,131,510	Grand Forks						
6,819,220	Minot						
6,639,882	Loring						
6,197,336				Langley			
5,857,593							Nellis
5,669,201	Ellsworth						
5,051,954						Barksdale	
4,912,365						Homestead	
4,809,473							Shaw
4,514,473				Beale			
4,277,465		Mountain Home					
3,505,279			Whiteman				

Data Description and Collection

Data Description

A necessary prerequisite to performing a linear regression analysis is the acquisition of data. The data collection effort was designed to provide information regarding the pertinent measurement parameters which are defined below for the benefit of the reader.

1. Electrical Consumption. Data for this dependent variable was measured in million British thermal units (Btu), and represents the amount of electrical energy used by an Air Force installation over a specified period. Electrical consumption is normally measured in kilowatt-hours with 11,600 Btu being equal to one kilowatt-hour (26:28). This conversion factor is used by the Air Force and the U.S. Department of Energy and represents the energy equivalent at the source of production (i.e., power plant) as distinguished from the point service or delivered energy equivalent of 3,413 Btu per kilowatt hour (34). Electrical energy consumed can include electricity purchased from a commercial supplier or electricity produced and used on the base or both. By virtue of the nature of the energy form, electricity is not stored for later use by facilities. Also, recorded consumption pertains only to use by facilities and not vehicles nor aircraft.

2. Heating Degree Days. Data for this independent variable was recorded daily and monthly by bases. Heating

degree days occurs when the mean daily temperature is below 65°F. In other words, a day with a mean temperature of 50°F was a day with fifteen heating degree days.

3. Cooling Degree Days. Data for this independent variable was recorded daily and monthly by bases. Like heating degree days, cooling degree days were computed based on the departure of the mean daily temperature from 65°F. A day with a mean daily temperature of 75°F was a day with ten cooling degree days. In cases where the average temperature was lower than 65°F, zero cooling degree days were recorded. Negative numbers were not used for cooling degree days or heating degree days.

3. Base Population. Data requested for this independent variable represents the sum total of military and civilian employees, contractor personnel and Non-Appropriated Fund (NAF) employees who work on the Air Force installation. Population data also includes the number of family housing occupants living in military family housing quarters.

4. Square Footage of Facilities. Data for this independent variable records the aggregate square footage of facilities in all category codes (which delineate how a facility is used) and condition codes (which distinguish between the physical and structural condition of buildings) as outlined in Air Force Manual 93-1, Air Force Real Property Accountable Records. Because no breakout was

available which reflected meter electrical use in specific facilities, all facilities making up the aggregate total of facility square footage were assumed to consume electricity in equal amounts.

Data Collection

The actual collection of the data defined above was requested for bases in SAC, TAC, ATC, AFLC, MAC and AFSC and when available was provided by the sources listed below:

1. Electrical Consumption. The Air Force Engineering and Services Center, Energy Group (AFESC/DEB), at Tyndall AFB, Florida provided, upon request, electrical consumption data by month for bases of interest. This data is listed in the Defense Energy Information System II (DEIS II) Report, which is stored in the main computer at Eglin AFB, Florida which provides computer support to the AFESC/DEB. As a matter of interest, the DEIS II also shows monthly consumption figures for all facility energy such as coal, electricity, fuel oil, natural gas, propane and purchased steam and hot water.

2. Heating Degree Days (HDD). The researcher, with extensive coordination and support from the Air Force Engineering and Services Center at Tyndall, secured monthly figures for HDD data from MAJCOM Deputy Chiefs of Staff, Engineering and Services, Directorate of Operations and

Maintenance. In a few instances, certain major air commands' civil engineering staffs did not have this data available. Partial data on HDD were provided for selected SAC bases from the Air Force Environmental Technical Applications Center (ETAC/ENE) at Scott AFB, Illinois. Because of the frequent and careful validation of input data into the ETAC computer, the AFESC considered ETAC the most reliable source of collecting both heating and cooling degree data (34).

3. Cooling Degree Days (CDD). The same sources were used for cooling degree days as for heating degree days.

4. Base Population. Data for base population, by fiscal year quarters, was requested for bases in the sample from the parent major air command historian's office. (Prior to that request, numerous other offices within Headquarters Air Force, AFESC, and various major air commands were approached for population data but without success.) The lack of reliable population data from the major air command was the single largest factor in limiting the sample size.

Data Analysis

Before any statistical analysis was accomplished, the data was visually inspected. Conflicting data from different sources was resolved by contacting the sources of the information. The data was next consolidated from the various sources onto worksheets, with data for all variables pertaining to a certain base on one worksheet.

The first objective of the data analysis was to determine the bivariate correlation between a base's electrical consumption and the four independent variables mentioned earlier.

Correlation

Bivariate correlation provides a single number which indicates the degree to which variation in one variable is related to variation in another. A correlation coefficient not only summarizes the strength of a linear association between a pair of variables, but also provides a means for comparing the strength of a linear relationship between one pair of variables and a different pair (17:276).

The Pearson correlation coefficient (r), used to quantify this strength of relationships between variables, takes on a value of +1.0 to -1.0. The larger the absolute value of r, the stronger the linear relationship between two variables. If r is positive, the two variables tend to increase (or decrease) together. A negative r denotes an inverse relationship, as one variable increases, the other variable tends to decrease.

By assuming that the populations are normally distributed, a test of the statistical significance of the estimate of the population correlation coefficient (ρ_{xy}), can be used to test the hypotheses:

$$H_0: \quad \rho_{xy} = 0$$
$$H_1: \quad \rho_{xy} \neq 0$$

The PEARSON CORR subprogram of the Statistical Package for the Social Sciences (SPSS), version 8, was used to calculate the correlation coefficients (17). SPSS reported the significance tests for each r (r being an estimate of the population parameter ρ_{xy}). The level of significance was derived from use of the Student's t distribution with n-2 degrees of freedom for the computed quantity:

$$t_s = r\left[\frac{n-2}{1-r^2}\right]^{\frac{1}{2}}$$

where n was the number of points correlated. The significance of each correlation was evaluated at the α=0.05 level. If the significance level of r was less than 0.05, then the correlation was considered statistically significant.

Multiple linear correlation (R), used in this research effort, represents an extension of the techniques for handling the relationship between only two variables to the set of methods for handling the relationship between more than two variables (12:422). The total variation or sums of squares in Y (dependent variable), can be partitioned into two components, one that was explained by the regression, (SS_{reg}), and another that was unexplained, (the sum of squared residuals, SS_{res}):

$$SS_y = SS_{reg} + SS_{res}$$

Mathematically, $R_{y \cdot x_1, x_2, \ldots, x_m}$, represents the multiple correlation between a dependent variable Y and a group of m variables $x_1, x_2, \ldots, x_m$, and was defined as follows:

$$R_{y \cdot x_1, x_2, \ldots, x_m} = \sqrt{\frac{SS_{reg}}{SS_y}}$$

Multiple correlation coefficients were calculated using the REGRESSION subprogram contained in the SPSS, version 8. The closer the value of R is to one, the more variation in the dependent variable is explained by inclusion of independent variables in the linear model.

Regression

The second objective of the research involves actual development of the model by building upon information found by satisfying objective number 1. The general form of the multiple linear regression model is:

$$Y_i = B_0 + B_1 x_{i,1} + B_2 x_{i,2} + \ldots + B_k x_{i,k} + e_i$$

$$i = 1, 2, \ldots, n$$

where:

Y_i = value of the dependent variable (electrical consumption) in the ith observation;

$B_0, B_1, B_2, \ldots, B_k$ = population regression parameters;

$x_{i,j}$ = value in the ith observation of the jth independent variable (heating degree days, cooling degree days, base population, square footage of facilities), j=1,2,...,k independent variables;

e_i = random error term in the ith observation; and

n = number of sample observations.

In development of a forecasting model, it was considered necessary to have an understanding of the factors influencing forecasting accuracy. Harnett (12:411) discussed the following necessary assumptions about the errors (e_i) in the population regression model:

1. The random error terms e_i are uncorrelated.

2. The expected value of e_i for the ith observation is zero.

3. The variance of e_i is constant for all observations.

4. The distribution of e_i is normal.

5. The number of sample observations is greater than the number of population regression parameters (k+1).

6. The independent variables are linearly independent.

7. Observational errors are associated with the dependent variable only.

The SPSS REGRESSION subprogram, which was used to develop the model, offered the option of forward (stepwise) inclusion. This option provided for the isolation of a subset of the independent variables which yielded an optimal MLR equation containing the fewest possible terms. The order in which the independent variables were included in the equation was determined by their respective contribution to the explanatory power of the model. The output of the SPSS REGRESSION subprogram provided not only the MLR model itself but also the statistical information required to evaluate it.

Multicollinearity

Multicollinearity refers to the situation in which some or all of the independent variables are intercorrelated. Variables that exhibit multicollinearity reduce the ability to account for the explanatory power of the particular independent variable in the model.

Coefficient of Determination

The coefficient of determination (R^2) is a measure of the relative ability of the MLR model to forecast values for the dependent variable given values for the independent variables. The SPSS forward inclusion option utilizes this measure in determining the order in which independent variables are entered. It is defined by the following ratio:

$$R^2 = \frac{\text{Explained Variation (EV)}}{\text{Total Variation (TV)}}$$

where,

$$TV = \Sigma Y_i^2 - \frac{(\Sigma Y_i)^2}{n}$$

$$EV = TV - \Sigma e_i^2$$

If the regression line is a "good" fit, explaining a large percentage of the variation between the dependent and independent variables, then R^2 approaches one. R^2 is the square of the multiple correlation coefficient R mentioned earlier.

<u>Significance of the Overall Regression</u>

The *significance* of the ability of the MLR model to explain variability in electrical consumption can be determined utilizing the following test of the second research hypothesis:

$$H_0\colon B_1 = B_2 = \ldots B_k = 0$$

Electrical energy consumption is not linearly related with heating and cooling degree days, base population and facility square footage.

$$H_1\colon \text{At least one } B_j \neq 0 \qquad j=1,2,3,4$$

Electrical consumption is linearly related to one or more of the independent variables.

The appropriate test statistic for the overall regression model is the F ratio which is given by the following:

$$F_0 = \frac{R^2 k}{(1-R^2)/(n-k-1)} = \frac{\text{Mean Square Regression}}{\text{Mean Square Error}}$$

where,

k = number of independent variables.

The test is conducted as a one-tailed test to the right; i.e., reject H_0 if $F_0 > F_{\alpha,k,n-k-1}$ where α is the level of significance (α=0.01), 1-α is the confidence level (17:335), k is the numerator degrees of freedom and n-k-1 is the denominator degrees of freedom.

Assumptions

Pertinent assumptions made for this research were as follows:

1. All data obtained from valid, official Air Force sources is accurate and correctly reflects the real world.

2. The data on electrical energy demanded in the DEIS II report corresponds to the same square footage that consumed the electrical energy.

3. The basic assumptions of multiple linear regression, as enumerated in this chapter were applicable.

4. Newly constructed facilities on the report of square footage are assumed to have been used throughout the full year.

5. Facility electrical energy related to geographically separated units is included in the research effort under the respective main operating base.

6. Data provided for base population is assumed to have included the sum total of military and civilian employees, contractor personnel and Non-Appropriated Fund employees who work on the Air Force installation. Base population data was also assumed to include military family housing occupants.

7. Data related to the sample of bases is assumed to be representative of bases in the population.

Limitations

Basic limitations on this research were as follows:

1. The independent variables were limited to those which data was unclassified and could be secured within the time provided.

2. The research effort may not adequately address the affects of force changes, weapon system changes and mission beddowns. Specifically, a mission change involving neither additional facility square footage nor additional base population could still alter the base's electrical consumption through the use of additional electrically supplied test equipment.

3. Data related to electrical energy consumption for a majority of the bases in the Air Force were not analyzed.

4. The number of data points varied with many bases due to voids in data supplied by others.

5. The separate effects of process energy (electrical energy required over and above lighting and creature comfort) may not be fully addressed by the assumptions and results of this research effort.

CHAPTER IV

RESULTS

Introduction

The first objective of this research effort was to determine if there is a relationship between an Air Force base's electrical consumption and the respective heating and cooling degree days, total square footage of real property facilities, and the base population. Achieving this objective was accomplished by examination of statistical significance of the coefficients of correlation between the dependent variable (electrical consumption) and the independent variables (heating and cooling degree days, base population and square footage of facilities).

The second objective was to develop a multiple linear regression model to forecast electrical consumption at an Air Force base. Multiple linear regression was performed for the one dependent variable and all four independent variables with the goal of establishing a predictor equation to fulfill this objective. These analyses and their results are presented in detail in this chapter.

Analysis

Objective Number 1

Objective number 1 was met by testing the hypothesis concerning the correlations between electrical consumption and the independent variables mentioned earlier.

Hypothesis 1. Hypothesis 1, developed at the end of Chapter I, is presented again: *Square footage of facilities, base population, and heating and cooling degree days are correlated with the electrical consumption of an Air Force base.*

This hypothesis was tested through the use of three related research questions. For the first research question, *What is the correlation between heating degree days and electrical consumption?*, Pearson correlation coefficients were calculated by the PEARSON CORR subprogram of SPSS and are shown in Table 4.1. This table shows that heating degree days and electrical consumption exhibit statistical significance (at $\alpha=0.05$) of correlation for all the bases in the sample, except Mountain Home AFB and Whiteman AFB. A point of note, however, is the apparent change of correlation of electrical consumption and heating degree days. Specifically, bases in colder climates (i.e., DOD Climate Zones of lower numbers), which experience a relatively larger amount of heating degree days, have predominently positive correlations between electrical

TABLE 4.1

PEARSON CORRELATION COEFFICIENTS (r) BETWEEN ELECTRICAL CONSUMPTION (EC) AND HEATING DEGREE DAYS (HDD) FOR SAMPLE BASES IN RESPECTIVE DEPARTMENT OF DEFENSE (DOD) CLIMATE ZONES

Base Name	DOD Climate Zone[a]	r (EC with HDD)	Number of Observations
Grand Forks AFB	1	.8315	57
Minot AFB	1	.8970	57
Loring AFB	1	.9305	60
Ellsworth AFB	1	.6701	57
Offutt AFB	2	-.6499	57
Mountain Home AFB	2	N/S[b]	60
Whiteman AFB	3	N/S	57
Beale AFB	4	.7265	50
Langley AFB	4	-.3202	72
Robins AFB	4	-.4628	39
Kelly AFB	6	-.6034	36
Homestead AFB	6	-.5963	60
Barksdale AFB	6	-.6168	57
Nellis AFB	7	-.5979	59
Shaw AFB	7	-.6008	60

[a]The lower the number of the DOD Climate Zone, the higher the annual total of Heating Degree Days (i.e., "colder" climates). Bases in DOD Climate Zones of higher numbers (i.e., Zones 6 and 7) reflect "warmer" climates.

[b]N/S denotes insufficient statistical significance at $\alpha=0.05$.

consumption and heating degree days. Bases in warmer climates (i.e., DOD Climate Zones of higher numbers) reflect negative correlation between heating degree days and electrical consumption.

The second research question is as follows: *What is the correlation between cooling degree days and electrical consumption?* Table 4.2 reflects the Pearson correlation coefficients for all the bases included in the sample. According to Table 4.2, cooling degree days and electrical consumption exhibit statistical significance (at α=0.05) for all the bases in the sample except Beale AFB. The correlation once again reflects a change in sign, only this time from negative correlations at colder bases to positive correlation at warmer bases.

The third research question is stated as follows: *What is the correlation between base population and electrical consumption?* Calculation of the Pearson correlation coefficient for electrical consumption and base population for the sample bases, reveals only one base, Loring AFB, has any correlation (r=0.3377) at the α=0.05 level of significance.

Research question number 4 is as follows: *What is the correlation between total square footage of facilities and electrical consumption?* Computation of the Pearson correlation coefficient for electrical consumption and total square footage of facilities reveals only three

TABLE 4.2

PEARSON CORRELATION COEFFICIENTS (r) BETWEEN ELECTRICAL CONSUMPTION (EC) AND COOLING DEGREE DAYS (CDD) FOR SAMPLE BASES IN RESPECTIVE DEPARTMENT OF DEFENSE (DOD) CLIMATE ZONES

Base Name	DOD Climate Zone[a]	r (EC with CDD)	Number of Observations
Grand Forks AFB	1	-.5665	57
Minot AFB	1	-.5048	57
Loring AFB	1	-.6587	60
Ellsworth AFB	1	-.2644	57
Offutt AFB	2	.3050	57
Mountain Home AFB	2	.5071	60
Whiteman AFB	3	.6299	57
Beale AFB	4	N/S[b]	50
Langley AFB	4	.8193	72
Robins AFB	4	.8526	39
Kelly AFB	6	.9039	36
Homestead AFB	6	.9657	60
Barksdale AFB	6	.9567	57
Nellis AFB	7	.9322	59
Shaw AFB	7	.8996	60

[a]The higher the number of the DOD Climate Zone, the higher the annual total of Cooling Days (i.e., "warmer" climates). Bases in DOD Climate Zones of lower numbers (i.e., Zones 1 and 2) are indicative "colder" climates.

[b]N/S denotes insufficient statistical significance at $\alpha=0.05$.

bases that have any significant correlation. Specifically, Whiteman AFB, Langley AFB and Nellis AFB exhibited correlations of -.5524, .3792 and .2730 respectively.

Table 4.3 is a summary table of all the correlation coefficients of each of the independent variables for each base in the sample. It shows only correlation coefficients significant at the $\alpha=0.05$ level.

Summary

The data provided a statistical basis for rejecting the null hypothesis

$$H_0: \quad \rho_{xy} = 0$$

for two of the four variables examined. Table 4.3 shows the correlations for heating degree days and cooling degree days to substantiate Hypothesis 1, whereas the insignificant correlations for population and square footage lead to rejection of Hypothesis 1 for these variables. A possible limitation should be addressed at this point. While the individual model results presented in Table 4.3 exhibit statistical significance at $\alpha=0.05$, there is a higher probability of an error of inference for at least one of the bases, if all fifteen bases are viewed collectively. While there is no apparent practical value to use the models collectively, it is necessary to caution against

TABLE 4.3

PEARSON CORRELATION COEFFICIENTS (r) BETWEEN ELECTRICAL CONSUMPTION (EC), HEATING DEGREE DAYS (HDD), COOLING DEGREE DAYS (CDD), BASE POPULATION (POP) AND FACILITY SQUARE FOOTAGE (SQ FT) FOR BASES IN SAMPLE

Base Name	EC with HDD r	EC with CDD r	EC with POP r	EC with SQ FT r	Number of Observations[a]
Grand Forks AFB	.8315	-.5665	N/S[b]	N/S	57
Minot AFB	.8970	-.5048	N/S	N/S	57
Loring AFB	.9305	-.6587	.3377	N/S	60
Ellsworth AFB	.6701	-.2644	N/S	N/S	57
Offutt AFB	-.6499	.3050	N/S	N/S	57
Mountain Home AFB	N/S	.5071	N/S	N/S	60
Whiteman AFB	N/S	.6299	N/S	-.5524	57
Beale AFB	.7265	N/S	N/S	N/S	50
Langley AFB	-.3202	.8193	N/S	.3792	72
Robins AFB	-.4628	.8526	N/S	N/S	39
Kelly AFB	-.6034	.9039	N/S	N/S	36
Homestead AFB	-.5963	.9657	N/S	N/S	60
Barksdale AFB	-.6168	.9567	N/S	N/S	57
Nellis AFB	-.5979	.9322	N/S	.2730	59
Shaw AFB	-.6008	.8996	N/S	N/S	60

[a] N/S denotes insufficient statistical significance at α=0.05.
[b] Observations consist of the number of monthly readings of EC, HDD, POP and SQ FT.

improperly inferring the significance would remain unchanged.

Objective Number 2

Objective number 2 was met by testing the hypothesis concerning the linear relationships between the dependent variable, electrical consumption, and the independent variables mentioned earlier.

Hypothesis 2. Hypothesis 2 is restated: *Consumption of electrical energy on an Air Force base can be predicted using heating and cooling degree days, base population and facility square footage, as independent variables.*

A stepwise regression of electrical consumption with heating and cooling degree days, base population and facility square footage was performed using the REGRESSION subprogram of SPSS as mentioned in Chapter III. Table 4.4 presents a summary of the results of the multiple linear regression models developed for each base. The model for each base was analyzed by evaluating the coefficient of determination (R^2) and tested using the F-test (as explained in Chapter III) at the 0.001 level of significance.

As Table 4.4 indicates, thirteen of the fifteen regression models developed during this research effort reveal a coefficient of determination above .650, meaning

TABLE 4.4

SUMMARY OF CONSTANTS AND COEFFICIENTS IN REGRESSION EQUATION FOR EACH BASE IN SAMPLE

Base Name	Constant	Heating Degree Days	Cooling Degree Days	Base Population	Facility Square Footage	Multiple R^2 Coefficient of Determination	Model Significance
Grand Forks AFB	169577.020	(1) 19.397	(3) -13.063	-	(2) -.006	-.696	< .001
Minot AFB	137523.800	(1) 19.147	(2) 33.704	(4) 1.044	(3) -.009	.826	< .001
Loring AFB	35703.795	(1) 12.749	(4) -2.125	(2) .869	(3) -.000	.875	< .001
Ellsworth AFB	33862.496	(1) 9.040	(2) 19.552	-	(3) .006	.724	< .001
Offutt AFB	-61228.869	(1) -24.258	(2) 43.557	(4) 0.746	(3) 0.021	.479	< .001
Mountain Home AFB	31630.077	(1) 42.947	(2) 7.160	(3) 2.384	-	.485	< .001
Whiteman AFB	366237.781	(3) 5.584	(1) 49.802	(4) .564	(2) -.092	.793	< .001
Beale AFB	59567.786	(1) -.662	(3) 24.447	(2) 9.505	(4) -.004	.950	< .001

TABLE 4.4--Continued

Base Name	Constant	Heating Degree Days	Cooling Degree Days	Base Population	Facility Square Footage	Multiple R^2 Coefficient of Determination	Model Significance
Langley AFB	5544.428	(2) 31.142	(1) 128.382	(4) -1.718	(3) .014	.877	< .001
Robins AFB	-10565.488	(2) 28.419	(1) 115.375	(3) 9.387	(4) -.004	.778	< .001
Kelly AFB	668903.924	(4) 6.241	(1) 128.663	(2) -9.459	(3) -.025	.836	< .001
Homestead AFB	5738.587	(2) 118.203	(1) 123.675	(4) -2.530	(3) .012	.970	< .001
Barksdale AFB	102702.501	(3) 5.606	(1) 99.211	(4) -.540	(2) -.010	.922	< .001
Nellis AFB	-7017.244	(3) 10.816	(1) 66.259	(4) -.781	(2) .013	.892	< .001
Shaw AFB	45210.286	(3) 3.555	(1) 79.246	(2) 2.589	(4) -.0009	.813	< .001

NOTE: Numbers in parentheses indicate order in which independent variables entered stepwise regression within each regression model.

that thirteen of the models explain better than 65 percent of the variation of the dependent variable. The model for Offutt and Mountain Home had the lowest R^2 with .479 and .485 respectively. It appears that these two models have not explained a very large amount of the variation using the same independent variables that the other models used. It is subjective evaluation of this author that the models for Offutt and Mountain Home do not provide enough explanation of the sample data points to be considered as good predictor models.

Table 4.4 also indicates the relative level of importance each independent variable had in the development of the regression model for each base in the sample population. In some instances (i.e., Grand Forks, Ellsworth, Mountain Home), the stepwise regression used did not allow some independent variables to enter the equation because the respective independent variable failed to explain enough additional variance in the sample. It is interesting to note (as Table 4.4 shows) that heating degree days appeared to enter the equation first for bases in colder climates. Conversely, cooling degree days entered the model first for bases in warmer climates. To assess the numerical significance of this phenomenon is difficult to accomplish due to possible multicollinearity between heating degree days and cooling degree days.

Table 4.5 shows a summary of intercorrelations between heating and cooling degree days, indicating the potential for multicollinearity. Since most of the values shown in Table 4.5 are near -.7000, there is evidence to suggest that multicollinearity exists.

Summary

All fifteen of the multiple linear regression models developed through use of the REGRESSION subprogram of SPSS were significant at a level of 0.001 or below. This significance was determined through the F-test described in Chapter III. Since the computed value of F exceeded the critical value of F for the 0.001 level of significance, data provided a statistical basis for rejecting the null hypothesis,

$$H_0: \ B_1 = B_2 = B_3 = B_4 = 0$$

and concluding H_1: at least one $B_j \neq 0$, for at least one or more of the independent variables.

TABLE 4.5

SUMMARY OF INTERCORRELATIONS BETWEEN HEATING DEGREE DAYS (HDD) AND COOLING DEGREE DAYS (CDD)

	Base	Correlation HDD with CDD
1.	Grand Forks AFB	-.64961
2.	Minot AFB	-.65315
3.	Loring AFB	-.68390
4.	Ellsworth AFB	-.67512
5.	Offutt AFB	-.16807
6.	Mountain Home AFB	-.66807
7.	Whiteman AFB	-.67576
8.	Beale AFB	-.74358
9.	Langley AFB	-.70604
10.	Robins AFB	-.69627
11.	Kelly AFB	-.70191
12.	Homestead AFB	-.72506
13.	Barksdale AFB	-.68575
14.	Nellis AFB	-.70068
15.	Shaw AFB	-.69692

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The well publicized energy crisis of the early 1970s left Americans apprehensive about the availability of energy supplies. The availabilty of commercially produced electrical power, which military installations are heavily dependent upon, is vulnerable to severe interruptions in the supply of imported oil. This fact, coupled with the uncertainty about the availability of future nuclear power, has resulted in certain regulatory changes.

Specifically, various Department of Defense and Air Force facility project improvement programs now exist allowing existing and new facilities to be more energy efficient to meet the energy reduction goals imposed by the Congress and the President. For the Air Force to effectively satisfy the goals of electrical energy conservation, it is necessary to identify those variables that influence an installation facility electrical consumption. Once identified, the variables should be included in a mathematical model to enable forecasting of electrical consumption with a reasonable degree of reliability. The current lack of a satisfactory method to predict electrical usage at Air Force bases has reduced our ability to effectively achieve energy conservation goals (34).

In view of the above, the first objective was to determine the correlation between variables suggested by reviewing current literature on the subject, and electrical consumption. Objective number 1 was accomplished, in that correlation coefficients exist between electrical consumption at an Air Force base and heating and cooling degree days for most of the bases in the sample population. There existed very little correlation between predicted electrical consumption and either base population or total facility square footage. Coefficients of correlation between electrical consumption and heating degree days appeared predominently positive for bases in colder climates whereas the values appeared predominently negative for bases in warmer climates. Of equal interest, coefficients of correlation between electrical consumption and cooling degree days reflected mostly negative values for bases in colder climates and primarily positive values for bases in warmer climates.

Objective number 2 was designed to develop a multiple linear correlation model utilizing the variables addressed in the first objective. Statistically significant models were developed for all fifteen bases in the sample population. All but three models included all of the four independent variables discussed in this research effort. While two models exhibited moderate coefficients of determination (.479 and .485), the thirteen remaining linear models exhibited R^2 between .696 to .970, reflecting the model's ability to explain between 69.6 percent to 97.0 percent of the variation. When viewed separately, heating degree days and cooling degree days exhibited a negative correlation varying from -.16807 at Offutt AFB to -.74358 at Beale AFB with the majority of values close to -.7000.

Conclusions

Multiple linear regression is the appropriate method to forecast the electrical consumption at an Air Force base. The author believes that the methodology can reasonably be extended to data at other bases. The overall capabilities of the models to forecast electrical consumption are, in my opinion, good predictors and of practical use to base level managers concerned with electrical energy consumption. It appears to me that base personnel interested in conserving electricity usage at bases in colder climates should focus attention on those consumption parameters related to heating degree days. Likewise, managers concerned with conserving electrical energy at bases in warmer climates might direct their efforts to those parameters related to cooling degree days. As a caution to the reader, statistically speaking, there is some potential for multicollinearity between the independent variables cooling degree days and heating degree days. With multicollinearity it could be possible to select a point that was within the range of observed heating degree days and cooling degree days individually, but outside the range of observed paired values of heating degree days and cooling degree days. However, from a practical standpoint, I do not believe that this will adversely affect the value of any individual model or reduce the model's prediction capability. Normally, when cooling degree days are high, heating degree days are low, and vice versa.

Nevertheless, base level managers now have a validated technique for developing a forecast model prepared for their specific base that will aid them in forecasting electrical consumption.

In a related data analysis effort, the author accomplished multiple linear regression using several combinations of the following transformed variables:

Population Times Cooling Degree Days

Cooling Degree Days Squared

Square Footage Times Cooling Degree Days

Square Footage Times Cooling Degree Days Squared

Square Footage Times Heating Degree Days

Heating Degree Days Squared

Square Footage Squared

Square Footage Times Heating Degree Days Times Population

Square Footage Times Heating Degree Days Squared

Square Footage Times Cooling Degree Days Times Population

A cursory review of the SPSS output by the author for several bases in the sample using transformed variables left the author with the opinion that multicollinearity between heating and cooling degree days tended to increase while the coefficient of determination for the model, R^2, tended to decrease. Consequently, it is the subjective opinion of the author that continued data analysis using the transformed variables mentioned above would prove fruitless.

Recommendations

The research effort surfaced some issues related to the subject that need further analysis. Specifically, those parameters related to heating degree days at colder bases and cooling degree days at warmer bases should be identified.

Further research in the area of electrical consumption may address an Air Force base's flying hours as an independent variable with the objective of exploring the effects that increased aircraft generations had on facility electrical consumption.

Additional research on the subject of electrical energy forecasting could involve developing a model using a temperature-humidity index which might appear to measure the discomfort of people due to the combined effects of high temperature and/or high humidity.

A forecasting model using the amount of precipitation as an independent variable could be compared to the results obtained in this research effort. It would be of value to determine if there are any effects on the intercorrelation between heating degree days and cooling degree days caused by using measured precipitation.

Another area of research in electrical energy forecasting that needs to be addressed concerns the price elasticity of commercially purchased electricity. Quantifying any apparent relationship between consumption and price could have advantages for base level managers concerned with budgeting for purchased electrical utilities. Specifically, the future effect of a price increase announced by the commercial power company could possibly enable base level managers to prepare utility budgets more accurately reflecting future consumption.

Further research concerning electrical energy forecasting might explore and quantify any relationship between facility projects completed under the Energy Conservation Investment Program (see Chapter I), and follow-on electrical consumption.

Additional research could evaluate models developed for bases in different Department of Defense Climate Zones in an effort to develop more generalized models that would apply to groups of installations in the same climatic zone with some other common denominator such as size or mission.

Another research effort could involve the use of a time series approach to forecast the independent variables. Then the forecasted independent variables could be analyzed using multiple linear regression in order to forecast electrical consumption.

Another recommendation for future research in forecasting electrical energy consumption could include solar insolation as an independent variable. Comparison of models between bases in geographical areas might highlight any difference solar insolation makes in electrical consumption with the goal of improving the coefficient of determination.

APPENDICES

APPENDIX A

DATA FILES FOR SAMPLE BASES

Data files for each of the fifteen sample bases are included in this appendix. Each line item entry represents one observation of the one dependent and four independent variables for a particular month and for a particular base. Although not used directly in this research effort, the respective Department of Defense (DOD) Climate Zone for each base is listed in each monthly observation for that base. The order in which each variable appears in the data does not change. An example of one entry in a data file is provided below along with an explanation of what each number represents.

820 =	2, 1, 19, 99679, 452, 9, 7413, 64665270
820 =:	Data line number assigned by the computer. This is not a variable, but used to keep data in order.
2:	Base number 2; in this case, Minot AFB.
1:	DOD Climate Zone 1. For definition of DOD Climate Zones, see Chapter III.
19:	This is the 19th monthly observation in the data file for Minot AFB.
99679:	Monthly electrical consumption, in mBtu, for the 19th month in the data file for Minot AFB.
452:	The total number of heating degree days that occurred in the 19th month at Minot AFB.
9:	The total number of cooling degree days that occurred in the 19th month for Minot AFB.

7413: The amount of base population reported for the 19th month for Minot.

64665270: The total facility square footage reported for the 19th month for Minot.

The different numbers used to distinguish one base from another in the data files are outlined below.

Number	Base
1	Grand Forks AFB
2	Minot AFB
3	Loring AFB
4	Ellsworth AFB
5	Offutt AFB
6	Mountain Home AFB
7	Whiteman AFB
8	Beale AFB
9	Langley AFB
10	Robins AFB
11	Kelly AFB
12	Homestead AFB
13	Barksdale AFB
14	Nellis AFB
15	Shaw AFB

Data File for Grand Forks AFB

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140=1,1,8,132194,318,5,6137,7491009
150=1,1,9,122473,71,113,6137,4791009
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180=1,1,12,111337,244,68,5814,7052870
190=1,1,13,121174,825,3,6346,7052870
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440=1,1,38,147900,1233,0,6382,7141678
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470=1,1,41,183736,1913,0,6325,7141678
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510=1,1,45,139606,106,49,6305,7136594
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Data File for Minot AFB

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Data File for Loring AFB

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1790=3,1,56,39138,454,0,4345,6332767
1800=3,1,57,35519,223,29,4345,6332767
1810=3,1,58,32921,78,47,4202,6332767
1820=3,1,59,32039,43,68,40,6332767
1830=3,1,60,36540,418,8,4202,6212488
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Data File for Ellsworth AFB

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1850=4,1,2,86516,942,0,6599,5864054
1860=4,1,3,79135,1089,0,6599,5864054
1870=4,1,4,70400,533,0,6633,5660540
1880=4,1,5,68974,306,3,6633,5660540
1890=4,1,6,69333,96,86,6633,5660540
1900=4,1,7,66120,1,283,6270,5660540
1910=4,1,8,72407,4,279,6270,5660540
1920=4,1,9,69787,116,106,6270,5457026
1930=4,1,10,66456,585,6,6583,5457026
1940=4,1,11,73938,961,0,6583,5457026
1950=4,1,12,74426,1138,0,6583,5457026
1960=4,1,13,77558,1595,0,6452,5457026
1970=4,1,14,78114,839,0,6452,5457026
1980=4,1,15,73092,872,0,6452,5606297
1990=4,1,16,65621,494,0,6464,5606297
2000=4,1,17,66166,157,37,6464,5606297
2010=4,1,18,58731,7,174,6464,5606297
2020=4,1,19,65320,0,318,6597,5606297
2030=4,1,20,70899,33,111,6597,5606297
2040=4,1,21,67129,135,67,6597,5755567
2050=4,1,22,66572,448,0,6929,5755567
2060=4,1,23,72376,958,0,6929,5755567
2070=4,1,24,75458,1387,0,6929,5755567
2080=4,1,25,82522,1725,6,7080,5755567
2090=4,1,26,78258,1443,0,7080,5755567
2100=4,1,27,74426,897,0,7080,5739620
2110=4,1,28,66677,559,0,7142,5739620
2120=4,1,29,72117,289,14,7142,5739620
2130=4,1,30,67268,103,89,7142,5739620
2140=4,1,31,65389,22,211,7120,5739620
2150=4,1,32,73126,33,210,7120,5739620
2160=4,1,33,71178,111,172,7120,5723674
2170=4,1,34,68266,425,0,7125,5723674
2180=4,1,35,72662,1063,0,7125,5723674
2190=4,1,36,78230,1428,0,7125,5723674
2200=4,1,37,63334,1781,0,7052,5723674
2210=4,1,38,81258,1401,0,7052,5723674
2220=4,1,39,74507,960,0,7052,5723674
2230=4,1,40,75458,670,1,6980,5723674
2240=4,1,41,68196,408,9,6980,5723674
2250=4,1,42,66259,99,90,6980,5723674
2260=4,1,43,70134,8,163,6762,5723674
2270=4,1,44,70412,46,132,6762,5723674
2280=4,1,45,64461,81,107,6762,5723674
2290=4,1,46,66920,445,3,6678,5723674
2300=4,1,47,73068,994,0,6678,5723674
2310=4,1,48,73382,991,0,6678,5723674
2320=4,1,49,77824,1399,0,6747,5723674
2330=4,1,50,79634,1122,0,6747,5723674
2340=4,1,51,74379,1079,0,6747,5696438
2350=4,1,52,77326,518,6,6759,5696438
2360=4,1,53,73068,250,30,6759,5696438
2370=4,1,54,71827,51,142,6759,5696438
2380=4,1,55,79344,0,385,6716,5696438
2390=4,1,56,78404,14,183,6716,5696438
2400=4,1,57,76862,135,74,6716,5669201
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Data File for Offutt AFB

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2430=5,2,3,124317,1110,0,12223,9121313
2440=5,2,4,108100,303,17,12354,9333457
2450=5,2,5,151763,201,18,12354,9333457
2460=5,2,6,152053,12,191,12354,9333457
2470=5,2,7,163340,0,366,11316,9333457
2480=5,2,8,167875,0,339,11318,9333457
2490=5,2,9,130674,62,140,11318,9545600
2500=5,2,10,111685,488,24,13629,9545600
2510=5,2,11,130825,910,0,13629,9545600
2520=5,2,12,129009,1219,0,13629,9545600
2530=5,2,13,141172,1565,0,13594,9545600
2540=5,2,14,124862,884,0,13594,9545600
2550=5,2,15,137611,605,0,13594,9542992
2560=5,2,16,113448,211,38,14093,9542992
2570=5,2,17,137216,6,185,14093,9542992
2580=5,2,18,153065,0,321,14093,9542992
2590=5,2,19,165,4740,479,14202,9542992
2600=5,2,20,164070,1,222,14202,9542992
2610=5,2,21,131753,24,85,14202,9540363
2620=5,2,22,117311,343,0,14261,9540363
2630=5,2,23,134931,755,0,14261,9540363
2640=5,2,24,130082,1168,0,14261,9540363
2650=5,2,25,144687,1586,0,14477,9540363
2660=5,2,26,123598,1374,0,14477,9540363
2670=5,2,27,129398,955,3,14477,9665228
2680=5,2,28,111627,391,5,14498,9665228
2690=5,2,29,142935,166,75,14498,9665228
2700=5,2,30,190878,12,259,14496,9665228
2710=5,2,31,205158,0,305,14449,9665228
2720=5,2,32,208104,4,277,14449,9665228
2730=5,2,33,91234,45,204,14449,9790093
2740=5,2,34,128818,358,5,14166,9790093
2750=5,2,35,127287,779,0,14166,9790093
2760=5,2,36,120686,1249,0,14166,9790093
2770=5,2,37,154013,1708,0,14095,9790093
2780=5,2,38,129850,1410,0,14095,9790093
2790=5,2,39,130291,874,0,14095,9730605
2800=5,2,40,125384,511,0,13999,9730605
2810=5,2,41,129073,181,41,13999,9730605
2820=5,2,42,141996,25,185,13999,9730605
2830=5,2,43,171657,5,264,13827,9730605
2840=5,2,44,173838,8,319,13827,9730605
2850=5,2,45,134931,48,126,13827,9671117
2860=5,2,46,134606,373,5,13604,9671117
2870=5,2,47,128122,821,0,13604,9671117
2880=5,2,48,134827,1005,0,13604,9671117
2890=5,2,49,139896,1218,0,13502,9671117
2900=5,2,50,132136,1192,0,13502,9671117
2910=5,2,51,135697,936,0,13502,9708507
2920=5,2,52,125094,419,11,13720,9708507
2930=5,2,53,130802,136,68,13720,9708507
2940=5,2,54,159187,11,229,13720,9708507
2950=5,2,55,187027,0,452,13766,9708507
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2970=5,2,57,135765,84,132,13766,9745897
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Data File for Mountain Home AFB

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3010=6,2,4,50727,1095,0,4238,4167902
3020=6,2,5,53592,927,0,4238,4167902
3030=6,2,6,46713,924,0,4238,4210990
3040=6,2,7,45820,510,0,4251,4210990
3050=6,2,8,43024,162,14,4251,4210990
3060=6,2,9,47479,99,85,4251,4210990
3070=6,2,10,53998,1,339,4288,4210990
3080=6,2,11,53754,30,141,4288,4210990
3090=6,2,12,47467,81,59,4288,4254078
3100=6,2,13,43825,436,2,4313,4254078
3110=6,2,14,47432,759,0,4313,4254078
3120=6,2,15,49404,1136,0,4313,4254078
3130=6,2,16,51179,1361,0,4272,4254078
3140=6,2,17,53035,845,0,4272,4254078
3150=6,2,18,43941,796,0,4272,4218818
3160=6,2,19,43628,298,30,4217,4218818
3170=6,2,20,39892,339,10,4217,4218818
3180=6,2,21,42560,15,200,4217,4218818
3190=6,2,22,50402,9,249,4605,4218818
3200=6,2,23,56968,41,290,4605,4218818
3210=6,2,24,46029,164,46,4605,4183558
3220=6,2,25,43906,469,0,4820,4183558
3230=6,2,26,45588,753,0,4820,4183558
3240=6,2,27,47757,937,0,4820,4183558
3250=6,2,28,51133,924,0,4773,4183558
3260=6,2,29,49625,827,0,4773,4183558
3270=6,2,30,44196,521,0,4773,4222496
3280=6,2,31,45205,460,0,4743,4222496
3290=6,2,32,46075,302,8,4743,4222496
3300=6,2,33,47688,68,83,4743,4222496
3310=6,2,34,50286,0,286,4751,4222496
3320=6,2,35,62582,42,231,4751,4222496
3330=6,2,36,46952,165,65,4751,4261433
3340=6,2,37,46098,350,4,4736,4261433
3350=6,2,38,45588,879,0,4736,4261433
3360=6,2,39,52478,1206,0,4736,4261433
3370=6,2,40,54164,1448,0,4575,4261433
3380=6,2,41,53279,827,0,4575,4261433
3390=6,2,42,46388,696,0,4575,4269449
3400=6,2,43,47873,555,0,4593,4269449
3410=6,2,44,42756,240,16,4593,4269449
3420=6,2,45,46284,141,117,4593,4269449
3430=6,2,46,57849,1,350,4579,4269449
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3450=6,2,48,47050,23,101,4579,4277465
3460=6,2,49,43245,332,6,4602,4277465
3470=6,2,50,43709,876,0,4602,4277465
3480=6,2,51,49636,915,0,4602,4277465
3490=6,2,52,50959,928,0,4568,4277465
3500=6,2,53,48836,764,0,4568,4277465
3510=6,2,54,43152,746,0,4568,4277465
3520=6,2,55,47305,426,0,4699,4277465
3530=6,2,56,42120,322,6,4699,4277465
3540=6,2,57,46481,147,65,4699,4277465
3550=6,2,58,49393,1,244,4699,4277465
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3570=6,2,60,48244,118,32,4699,4277465
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Data File for Whiteman AFB

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3610=7,3,4,63522,285,26,3870,3360462
3620=7,3,5,58847,170,28,3870,3360462
3630=7,3,6,68649,4,186,3870,3360462
3640=7,3,7,78706,0,437,3776,3360462
3650=7,3,8,85724,0,371,3776,3360462
3660=7,3,9,77639,31,186,3776,3345888
3670=7,3,10,60529,440,35,3973,3345888
3680=7,3,11,62385,858,0,3973,3345888
3690=7,3,12,63023,1090,0,3973,3345888
3700=7,3,13,68080,1538,0,3913,3345888
3710=7,3,14,64229,817,0,3913,3345888
3720=7,3,15,57791,504,0,3913,3359656
3730=7,3,16,64322,174,34,3894,3359656
3740=7,3,17,60158,25,166,3894,3359656
3750=7,3,18,72581,0,283,3894,3359656
3760=7,3,19,79344,0,460,3859,3359656
3770=7,3,20,79472,0,363,3859,3359656
3780=7,3,21,77221,15,180,3859,3373424
3790=7,3,22,59288,267,11,3771,3373424
3800=7,3,23,59578,606,0,3771,3373424
3810=7,3,24,65053,1035,0,3771,3373424
3820=7,3,25,67941,1406,0,4723,3373424
3830=7,3,26,65749,1226,0,4723,3373424
3840=7,3,27,63313,821,4,4723,3372525
3850=7,3,28,62269,263,14,4628,3372525
3860=7,3,29,56921,159,96,4628,3372525
3870=7,3,30,69055,5,288,4628,3372525
3880=7,3,31,81455,0,436,4424,3372525
3890=7,3,32,74136,0,312,4424,3372525
3900=7,3,33,82743,32,262,4424,3371625
3910=7,3,34,60494,296,12,4350,3371625
3920=7,3,35,61747,586,4,4350,3371625
3930=7,3,36,63197,971,0,4350,3371625
3940=7,3,37,68997,1465,0,4306,3371625
3950=7,3,38,71769,1139,0,4306,3371625
3960=7,3,39,59334,671,0,4306,3438452
3970=7,3,40,58267,381,6,4352,3438452
3980=7,3,41,54949,111,65,4352,3438452
3990=7,3,42,57930,3,218,4352,3438452
4000=7,3,43,62199,2,341,4138,3438452
4010=7,3,44,66259,4,341,4138,3438452
4020=7,3,45,58429,38,126,4138,3505279
4030=7,3,46,47653,223,47,4038,3505279
4040=7,3,47,48871,655,0,4038,3505279
4050=7,3,48,47606,837,0,4038,3505279
4060=7,3,49,52884,1010,0,3895,3505279
4070=7,3,50,54242,1095,0,3895,3505279
4080=7,3,51,48210,778,0,3895,3505279
4090=7,3,52,47154,371,10,3912,3505279
4100=7,3,53,45878,124,52,3912,3505279
4110=7,3,54,58325,4,279,3912,3505279
4120=7,3,55,68324,0,621,3934,3505279
4130=7,3,56,76920,0,442,3934,3505279
4140=7,3,57,62570,57,173,3934,3505279
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Data File for Beale AFB

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4180=8,4,4,94737,228,1,5756,4577919
4190=8,4,5,90793,0,185,5756,4577919
4200=8,4,6,95039,1,288,5756,4577919
4210=8,4,7,109006,0,458,5541,4577919
4220=8,4,8,90062,0,293,5541,4577919
4230=8,4,9,86269,0,306,5541,4901663
4240=8,4,10,81664,39,107,5887,4901663
4250=8,4,11,90584,264,1,5887,4901663
4260=8,4,12,116626,582,0,5887,4901663
4270=8,4,13,133481,705,0,5812,4901663
4280=8,4,14,90677,349,0,5812,4901663
4290=8,4,15,102544,427,0,5812,4679584
4300=8,4,16,77662,81,12,5745,4679584
4310=8,4,17,82975,165,33,5745,4679584
4320=8,4,18,96883,4,376,5745,4679584
4330=8,4,19,105061,0,448,5688,4679584
4340=8,4,20,92800,0,410,5688,4679584
4350=8,4,21,92860,6,245,5688,4457504
4360=8,4,22,76876,52,70,5681,4457504
4370=8,4,23,90074,339,0,5681,4457504
4380=8,4,24,105015,464,0,5681,4457504
4390=8,4,25,109678,426,0,5731,4457504
4400=8,4,26,94157,334,0,5731,4457504
4410=8,4,27,89018,179,1,5731,4501235
4420=8,4,28,85828,192,8,5780,4501235
4430=8,4,29,81513,22,143,5780,4501235
4440=8,4,30,87035,0,139,5780,4501235
4450=8,4,31,102103,0,367,5755,4501235
4460=8,4,32,99122,0,357,5755,4501235
4470=8,4,33,81328,10,176,5755,4544966
4480=8,4,34,82557,34,123,5705,4544966
4490=8,4,35,98449,405,0,5705,4544966
4500=8,4,36,127612,694,0,5705,4544966
4510=8,4,37,124735,577,0,5675,4544966
4520=8,4,38,104052,410,0,5675,4544966
4530=8,4,39,96547,279,0,5675,4484328
4540=8,4,40,85132,201,0,5575,4484328
4550=8,4,41,92591,44,161,5575,4484328
4560=8,4,42,94923,1,316,5575,4484328
4570=8,4,43,105398,0,444,5430,4484328
4580=8,4,44,98913,0,376,5430,4484328
4590=8,4,45,94679,0,335,5430,4423690
4600=8,4,46,95074,97,90,5364,4423690
4610=8,4,47,98206,364,0,5364,4423690
4620=8,4,48,123354,521,0,5364,4423690
4630=8,4,49,127809,526,0,5199,4423690
4640=8,4,50,107810,332,0,5199,4423690
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Data File for Langley AFB

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4680=9,4,4,73962,616,1,9748,4884354
4690=9,4,5,70145,565,3,9748,4884354
4700=9,4,6,74472,535,1,9748,4684354
4710=9,4,7,71526,362,19,9857,5291977
4720=9,4,8,80678,57,133,9857,5291977
4730=9,4,9,104678,0,325,9857,5291977
4740=9,4,10,114283,0,366,9640,5291977
4750=9,4,11,118598,0,437,9640,5291977
4760=9,4,12,99342,5,225,9640,5291977
4770=9,4,13,78404,11,53,8310,5699601
4780=9,4,14,72071,305,15,8310,5699601
4790=9,4,15,93740,663,0,8310,5699601
4800=9,4,16,94378,834,0,9021,5699601
4810=9,4,17,83404,434,8,9021,5699601
4820=9,4,18,89540,465,10,9021,5699601
4830=9,4,19,84738,232,69,9085,5836224
4840=9,4,20,81513,81,84,9085,5836224
4850=9,4,21,115954,11,290,9085,5836224
4860=9,4,22,129734,0,417,9410,5836224
4870=9,4,23,130233,0,347,9410,5836224
4880=9,4,24,111476,16,140,9410,5836224
4890=9,4,25,89100,332,10,9958,5972847
4900=9,4,26,102312,656,0,9958,5972847
4910=9,4,27,101918,804,0,9958,5972847
4920=9,4,28,114689,1132,0,10111,5972847
4930=9,4,29,92301,656,0,10111,5972847
4940=9,4,30,84239,310,12,10111,5972847
4950=9,4,31,81826,153,51,10180,6069512
4960=9,4,32,98113,40,134,10180,6069512
4970=9,4,33,112044,3,294,10180,6069512
4980=9,4,34,134235,0,534,10296,6069512
4990=9,4,35,147262,0,476,10296,6069512
5000=9,4,36,120083,0,354,10296,6069512
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5020=9,4,38,86657,307,21,10283,6166176
5030=9,4,39,95201,665,0,10283,6166176
5040=9,4,40,107509,657,0,10130,6166176
5050=9,4,41,97289,962,0,10130,6166176
5060=9,4,42,96141,627,0,10130,6166176
5070=9,4,43,76096,253,9,9511,6181756
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Data File for Robins AFB

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Data File for Kelly AFB

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Data File for Homestead AFB

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AD-A109 880 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 12/1
DEVELOPMENT OF A MULTIPLE LINEAR REGRESSION MODEL TO FORECAST F--ETC(U)
SEP 81 F H WECK
UNCLASSIFIED AFIT-LSSR-68-81 NL

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A109880

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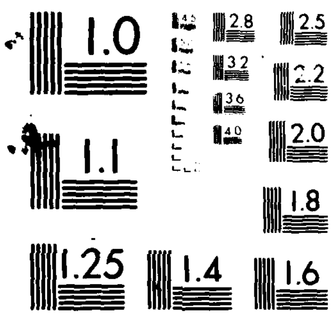

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

Data File for Barksdale AFB

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Data File for Nellis AFB

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Data File for Shaw AFB

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8270=15,7,40,59740,683,0,6185,4837831
8280=15,7,41,61468,610,0,6185,4837831
8290=15,7,42,62037,250,8,6185,4839265
8300=15,7,43,56214,57,49,6236,4839265
8310=15,7,44,69936,10,179,6236,4839265
8320=15,7,45,76862,0,308,6236,4839265
8330=15,7,46,98271,0,418,6366,4839265
8340=15,7,47,99041,0,428,6366,4839265
8350=15,7,48,69413,6,253,6366,4840698
8360=15,7,49,71247,123,55,5942,4840698
8370=15,7,50,53952,253,23,5942,4840698
8380=15,7,51,52826,549,0,5942,4840698
8390=15,7,52,60285,575,0,5389,4840698
8400=15,7,53,56828,620,0,5389,4840698
8410=15,7,54,55471,385,0,5399,4792169
8420=15,7,55,54729,98,68,5361,4792169
8430=15,7,56,61422,16,206,5361,4792169
8440=15,7,57,79831,0,326,5361,4792169
8450=15,7,58,102057,0,513,5361,4792169
8460=15,7,59,101798,0,614,5361,4792169
8470=15,7,60,99911,9,396,5361,4809473
```

APPENDIX B

SAMPLE OUTPUT FOR GRAND FORKS AFB

This appendix contains a sample output from the REGRESSION subprogram of the Statistical Package for the Social Sciences (SPSS) for Grand Forks AFB. Grand Forks represents a base from a cold climate, being situated in Department of Defense Climate Zone 1. As the Summary Table in the output shows, heating degree days was the first independent variable to enter the regression model, followed by cooling degree days and facility square footage. This output can be compared to the output for a base in a warm climate, Shaw AFB, which is shown in Appendix C.

Sample SPSS Output, Grand Forks AFB

```
VARIABLE           MEAN     STANDARD DEV     CASES

  EC           141859.0000       16756.5667        57
HDD              774.3684         689.3564        57
CDD               36.2807          56.8879        57
POP             6137.2982         619.3760        57
SQF          7118625.6140      380262.1929        57


  CORRELATION COEFFICIENTS.

  A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.


HDD          .83151
CDD         -.56651   -.64961
POP          .15047    .18786   -.08515
SQF          .09252    .11681   -.16151   -.05186

               EC         HDD       CDD       POP




  * * * * * * * * * M U L T I P L E   R E G R E S S I O N * * * * * * * * *

  DEP. VAR... EC         ELECTRICAL CONSUMPTION

  MEAN RESPONSE   141859.00000      STD. DEV.   16756.56668

  FINAL STEP.

  MULTIPLE R    .8323 ANOVA          DF  SUM SQUARES  MEAN SQ.      F
  SQUARE      .6927 REGRESSION     3.   .1009E+11   .36E+10   39.820
  D DEV   9548.4380 RESIDUAL      53.   .4832E+10   .91E+08 SIG.    0
 ADJ R SQUARE  .6753 COEFF OF VARIABILITY     6.7PCT

  VARIABLE        B       S.E. B       F     SIG.      BETA   ELASTICITY

  HDD         19.496     2.435    64.113     0       .68208     .10643
 CDD         -13.828    29.735      .216  .644     -.04688    -.00354
 SQF           -.000      .003      .013  .910     -.00674    -.01933
 CONSTANT 130005.923 24462.749    28.197  .000
```

Sample SPSS Output, Grand Forks AFB--Continued

COEFFICIENTS AND CONFIDENCE INTERVALS.

VARIABLE	B	95 PCT C.I.	
HDD	19.4965	14.6127	24.3803
CDD	-13.8280	-73.4698	45.8138
SQF	-.0004	-.0072	.0064
CONSTANT	.1E+06	.6E+05	.1E+06

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.

HDD	5.92879		
CDD	46.59453	884.19876	
SQF	-.00013	.01147	.00001
	HDD	CDD	SQF

* * * * * * * * * * M U L T I P L E   R E G R E S S I O N * * * * * * * * * *

DEP. VAR... EC   ELECTRICAL CONSUMPTION

SUMMARY TABLE.

STEP	VARIABLE	E/R	F	MULT-R	R-SQ	CHANGE	R	OVERALL F	SIG.
1	HDD	E	123.229	.832	.691	.691	.832	123.229	0
2	CDD	E	.211	.832	.693	.001	-.567	60.836	.000
3	SQF	E	.013	.832	.693	.000	.093	39.828	0

APPENDIX C

SAMPLE OUTPUT FOR SHAW AFB

This appendix contains a sample output from the REGRESSION subprogram of the Statistical Package for the Social Sciences (SPSS) for Shaw AFB. Shaw AFB represents a base from a warm climate, being situated in Department of Defense Climate Zone 7. As the Summary Table in the output shows, cooling degree days was the first independent variable to enter the regression model, followed by base population, heating degree days and total facility square footage. This output can be compared to the output for a base in a cold climate, Grand Forks, which is shown in Appendix B.

Sample SPSS Output, Shaw AFB

VARIABLE	MEAN	STANDARD DEV	CASES
EC	72203.6333	16965.8601	60
HDD	214.3833	262.0688	60
CDD	185.4500	200.2651	60
POP	6045.0000	308.9691	60
SQF	4723155.3167	251700.6126	60

CORRELATION COEFFICIENTS.

A VALUE OF 99.00000 IS PRINTED
IF A COEFFICIENT CANNOT BE COMPUTED.

	EC	HDD	CDD	POP
HDD	-.60083			
CDD	.89963	-.69692		
POP	.12528	-.09612	.08990	
SQF	.12056	-.05921	.14347	.05347

* * * * * * * * * M U L T I P L E   R E G R E S S I O N * * * * * * * * *

DEP. VAR... EC ELECTRICAL CONSUMPTION

MEAN RESPONSE 72203.63333 STD. DEV. 16965.86007

FINAL STEP.

MULTIPLE R	.9016	ANOVA	DF	SUM SQUARES	MEAN SQ.	F
SQUARE	.8130	REGRESSION	4.	.1380E+11	.34E+10	59.768
D DEV	7599.3194	RESIDUAL	55.	.3176E+10	.57E+08	SIG. .000
ADJ R SQUARE	.7994	COEFF OF VARIABILITY		10.5PCT		

VARIABLE	B	S.E. B	F	SIG.	BETA	ELASTICITY
CDD	79.246	6.961	129.584	0	.93551	.20354
POP	2.589	3.222	.646	.425	.04714	.21672
HDD	3.555	5.279	.453	.504	.05491	.01055
SQF	-.001	.004	.048	.828	-.01292	-.05697
CONSTANT	45210.286	26424.715	2.927	.093		

Sample SPSS Output, Shaw AFB--Continued

```
 COEFFICIENTS AND CONFIDENCE INTERVALS.

 VARIABLE        B            95 PCT C.I.

 CDD          79.2459     65.2946   93.1970
POP            2.5886     -3.8679    9.0452
HDD            3.5546     -7.0250   14.1345
SQF            -.0009      -.0089     .0071
CONSTANT       .4E+05     -.7E+04    .9E+05

VARIANCE/COVARIANCE MATRIX OF THE UNNORMALIZED REGRESSION COEFFICIENTS.


HDD         27.87012
CDD         25.52389  48.46223
POP           .83927   -.57251  10.37975
SQF          -.00125   -.00392   -.03656    .00022

               HDD       CDD       POP       SQF




 * * * * * * * * * M U L T I P L E   R E G R E S S I O N * * * * * * * * *

 DEP. VAR... EC          ELECTRICAL CONSUMPTION


SUMMARY TABLE.

 STEP VARIABLE E/R       F   MULT-R R-SQ CHANGE   R   OVERALL F  SIG.

   1  CDD       E    246.196  .900  .809  .809  .900  246.196     0
 2  POP       E        .600  .901  .811  .002  .125  122.550  .000
 3  HDD       E        .445  .902  .813  .001 -.601   81.053     0
 4  SQF       E        .048  .902  .813  .000  .121   59.766  .000
```

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